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Chapter 17

RADIO FREQUENCY SIGNAL DEGRADATION RELEVANT TO COMMUNICATIONS AND RADAR SYSTEMS

INTRODUCTION

Nuclear detonations can affect the performance of radio communication, radar, and other electronic systems that rely on electromagnetic-wave propagation. Usually, the effects will be deleterious although performance may occasionally be enhanced. Applicable nuclear-weapon-induced phenomena are discussed in Chapters 3, 5, and 8. Generally, each system and environmental situation of interest must be examined to determine whether nuclear weapons effects will be important and to what extent they will be important.

Electromagnetic waves propagating along paths entirely below 25 kilometers are not likely to be affected by nuclear-produced disturbances. When a detonation occurs below 25 kilometers, the major degradation region is the fireball, which is limited in extent. When a detonation occurs above 25 kilometers, very little of the weapon radiation penetrates below 25 kilometers and the effects that are produced are short-lived.

Electromagnetic waves propagating along paths above 25 kilometers can be affected severely by nuclear detonations. If the detonation occurs below 25 kilometers, the effects will be minimal, unless the weapon yield is so large that the fireball debris is carried well above 25 kilometers. As the detonation altitude is raised above 25 kilometers, propagation disturbances can cover a major portion of a hemisphere; they may last for hours, and they may interfere with systems that depend on the natural ionosphere to reflect or scatter energy, such as HF systems,

seriously. The size of the region affected and the duration of the effects on the system decrease with increasing wave frequency for frequencies above a few megahertz. Effects on wave frequencies above a few gigahertz are limited to the fireball region (a few tens to a few hundred kilometers in diameter).

As a result of the very large number of possible interactions between the effects caused by a nuclear burst and the electronic system in its operating environment, problems deriving from the degradation of signals in a nuclear environment are so complex that techniques for calculating signal degradation in nuclear environments are not appropriate for the subject material of this chapter. Such problems are performed most effectively with the aid of computers, using codes such as RANC 4 (see bibliography). Methods for computation of system performance by hand have been devised, but, in general, they are lengthy, even though many simplifications must be included. Some such computations for determining absorption are described in Chapter 8. Analyses of generic systems for selected burst conditions are useful for determining the nature and order of magnitude of effects; however, generalizations from such analyses are not warranted.

Although the English system of units for measuring distance is given priority throughout most chapters of this manual, wavelengths and other dimensions dealing with electromagnetic wave propagation usually are given in the metric system. Therefore, in this chapter and in Chapter 8, the metric system is used for distance dimensions. Conversion factors from the metric system to the English system are provided in Appendix B.

17-1

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As discussed in Chapter 8, considerable uncertainty exists in the prediction of the effects of nuclear weapon bursts on electromagnetic propagation, particularly for burst or propagation conditions different from those for which test data have been obtained. While in general the prediction of weapon effects is more difficult in a multiple-burst environment than for a single burst, system performance may be relatively insensitive to burst parameters; for such cases simple models of the disturbed environment can be used for analysis.

ic absorption regions caused by a nuclear detonation: the fireball, a region around the fireball, and the D-region of the ionosphere (approximately 50 to 80 km altitude). Figure 17-1 illustrates the absorption regions for several burst altitudes and times after burst.

SECTION I

DEGRADATION MECHANISMS

Nuclear weapon effects on electromagnetic propagation are grouped into three degradation mechanisms in this section: attenuation, which defines the change in the amount of electromagnetic energy reaching a given location; interference, which defines the level of noise competing with a received signal; and distortion, which defines the change in information content of a received signal.

ATTENUATION

Attenuation of signals in a nuclear environment derives principally from the phenomena of absorption, scattering, and beam spreading (small angle scattering, i.e., differential refraction or defocusing). In some instances, generally at times after detonation in excess of a few minutes, scattering and beam spreading can be the more important phenomena. For most cases, however, attenuation caused by absorption is regarded as one of the most important effects caused by nuclear detonations (see ELECTROMAGNETIC PROPAGATION IN IONIZED REGIONS in Chapter 8), and it is one of the best understood and most predictable of the effects. There are three principal atmospher-

17-1 Fireball Absorption

The fireball is generally the most intensely absorbing region. Significant absorption within the fireball can last tens of seconds for frequencies less than about 10 GHz (see paragraph 8-6). Fireball sizes vary from less than a kilometer for small-yield surface bursts to several hundred kilometers for large-yield, high-altitude bursts. The fireball size and location as a function of burst parameters can be determined from Table 8-2 and Figures 8-16 and 8-38. The amount of signal attenuation caused by absorption of signals propagating through the fireball can be determined from Tables 8-3 through 8-7. For many cases of interest in analyzing a system, the duration of attenuation due to fireball absorption is determined by the rise rate of the rising fireball rather than the length of time the fireball remains absorbing.

17-2 Absorption in the Region Around the Fireball

When the fireball is below the D-region, delayed gamma rays emitted from fission debris in the fireball cause ionization and thus absorption in a small region surrounding the fireball (see paragraph 8-8). The size of the region depends on the burst and propagation parameters; it can extend beyond the fireball for tens of kilometers for frequencies below a few gigahertz. Estimates of signal attenuation can be obtained from Figures 8-42 through 8-48 (Problem 8-6).

When the fireball is above the D-region, most of the absorption outside the fireball occurs in the D-region as discussed below.

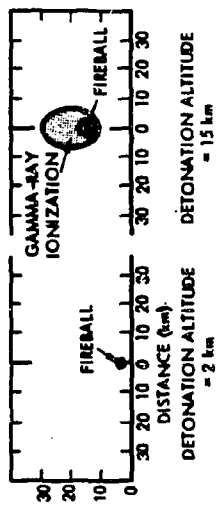
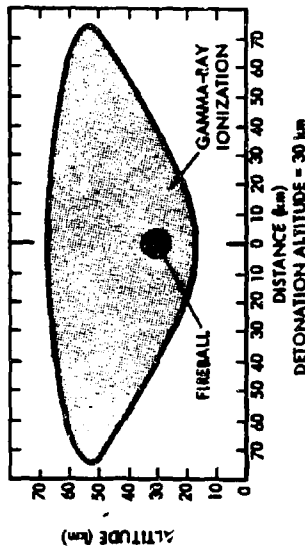
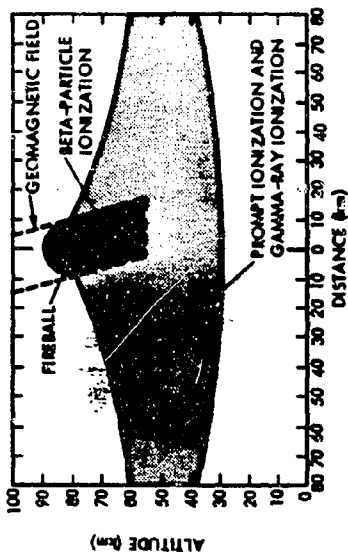
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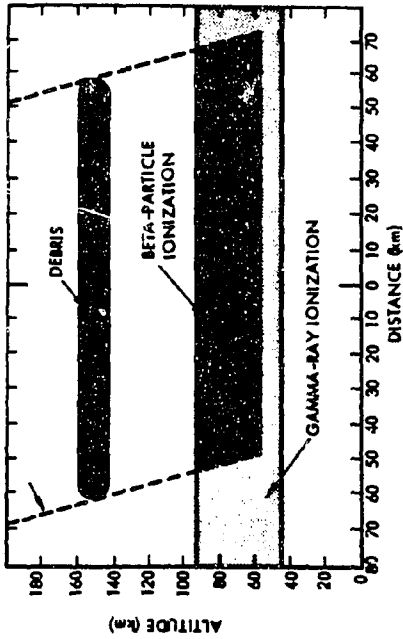
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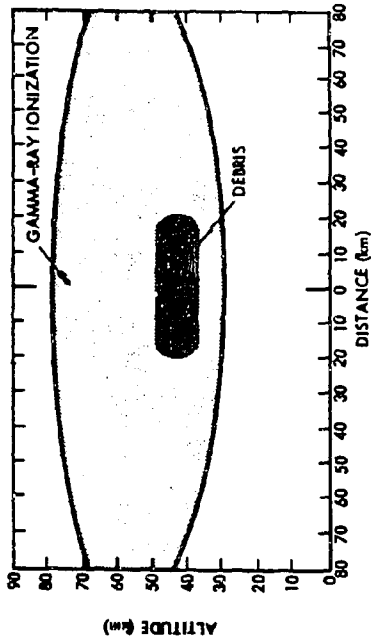
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LOCATIONS A FEW SECONDS AFTER BURST



DEBRIS ALTITUDE ABOVE 60 km



DEBRIS ALTITUDE BELOW 60 km

LOCATIONS A FEW MINUTES AFTER BURST

Figure 17-1. Approximate Locations of Ionization Causing Absorption

17-3 D-Region Absorption

The largest and most persistent absorption region caused by nuclear detonations generally occurs in the D-region. Depending on detonation altitude and weapon yield, both prompt radiation (X-rays and neutrons) and delayed radiation (beta particles and gamma rays) can ionize the D-region and cause absorption (see paragraphs 8-2 through 8-8). For frequencies above a few megahertz, absorption in the D-region is related inversely to the square of the frequency at which the system operates. The extent of D-region ionization caused by prompt radiation depends on the detonation altitude. The size of the ionized region increases from a few tens of kilometers for detonations below the D-region to thousands of kilometers for detonations above several hundred kilometers. The duration of significant absorption caused by ionization resulting from prompt radiation varies from less than a second for 1 GHz and nighttime conditions to tens of minutes for 10 MHz and daytime conditions.

Delayed gamma rays are an important D-region ionization source when the fission debris is above about 25 kilometers. The extent of the ionization increases with debris altitude. Large regions (thousands of kilometers in diameter) are affected when the debris is above several hundred kilometers in altitude. The larger ionization regions are primarily of importance for frequencies below a few hundred megahertz. Some of the Compton electrons produced in the burst region by gamma rays are guided by the geomagnetic field and produce ionization in the D-region on the opposite side of the magnetic equator (see paragraph 8-3). The resulting absorption is less intense than that due to gamma ray ionization in the burst region, but it can be important for frequencies in and below the HF band.

Beta particles ionize the D-region when the fission debris is above about 60 kilometers.

As illustrated in Figure 17-1 and discussed in paragraph 8-3, the size and location of the region ionized by beta-particles depend on the size and location of the debris region and the direction of the geomagnetic field. For each debris region above 60 kilometers there are two beta-particle absorption regions; one in the burst locale and one on the opposite side of the geomagnetic equator. At early times after burst when the debris region is relatively small (less than a few hundred kilometers in radius), beta-particle ionization can cause significant absorption for frequencies below a few gigahertz. At later times, when the debris is dispersed over large regions, the ionization is primarily important in causing absorption for frequencies below a few hundred megahertz.

Estimates of D-region absorption caused by prompt and delayed radiation can be obtained from Figures 8-40 through 8-51.

17-4 Absorption of Noise

Receiving system performance also may be affected if noise normally reaching the system via the ionosphere is absorbed. The noise level of some systems is determined by external sources (atmospheric noise, cosmic noise, or interfering signals from other sources) that propagate energy through the atmosphere. Both the desired signal and the undesired signal may be attenuated. The resulting signal-to-noise ratio depends upon the exact location of terminals, noise source, and weapon-produced ionization.

17-5 Attenuation by Scattering and Beam Spreading

Attenuation by absorption results when energy from a radio wave is deposited in the propagation medium in the form of heat. A different class of attenuation is that due to scattering of radio energy from the desired direction to other (possibly widely different) directions. A fundamental requirement for scattering is that

[REDACTED]

the refractive index of the medium be structured. Thus, regions of high electron-density gradient (e.g., fireball boundaries and various regions containing plasma striations) are of prime concern.

Characteristics of the electron-density structure that are important are its strength (i.e., the magnitude of spatial variation) and its size or scale. Generally, the greater the variation (especially in the integral of electron density along the line of sight), the greater the portion of energy scattered, and, the smaller the structure, the wider the scatter cone. The scale, relative to two parameters of the operating system, the wavelength and the Fresnel-zone radius, determine the nature of the attenuation effects associated with this scattering.

As a practical matter, the environments of concern seem to divide naturally, leading to a useful separation of effects into attenuation by scattering and attenuation by signal reduction through beam spreading. The former, loss by scattering, implies scattering at angles that are substantially larger than the system beamwidth. The latter, beam spreading, implies scattering, defocusing, or diffraction at angles comparable to or less than the system beamwidth.

The simplest effects to visualize are those due to structure that is large compared with both the wavelength and the Fresnel zone. These effects are refractive in nature and can be understood on the basis of ray optics. Simple ray bending may apparently displace a radio source from an antenna beam, resulting in attenuation, unless the beam is made to track the source. A patch of enhanced plasma will cause such ray bending in its border regions. In the mid-region of such a patch, the ray bending is minimum, but the radio energy density is actually decreased by defocusing, even if the source is kept in beam center. In effect, the plasma patch acts as a radio-frequency diverging lens. A region of lower-than-average electron density, on the

other hand, will act as a converging lens.

A region of plasma-density irregularities (e.g., fireball striations) may act as an ensemble of diverging and converging lenses, producing both attenuation and enhancement of signals. If the scale of the irregularities is small enough to be comparable with the system Fresnel zone at the range of the plasma, then they are too small to produce lenslike focuses, and the propagation must be treated by diffraction theory. The result regarding signal strength, however, still is to produce positive and negative fluctuations. This diffractive scatter can occur even if the irregularities are too weak to produce significant focuses or defocuses; the situation may be viewed intuitively as multipath propagation.

As the irregularity scale becomes smaller, the scatter cone becomes wider and can exceed the system beamwidth. In this case, not only will there be fluctuations in signal strength but also a net attenuation on the average. This net attenuation will occur whether the antenna achieves its directivity by employing a reflecting aperture (e.g., a dish antenna) or from phased elements distributed on the aperture (i.e., a phased array).

In the extreme, when the plasma structure becomes comparable in scale to the system wavelength, the radio energy is backscattered and lost to any receiver on the opposite side of the structured plasma, regardless of its antenna beamwidth. In this case, the attenuation effect is virtually indistinguishable from that due to absorption. Usually, the intensity of very small scale size fluctuations is small so that, although backscatter does occur — leading to radar clutter (paragraph 8-12) — such a small fraction of the energy goes into this phenomenon that the resulting attenuation of the primary beam is quite small. The presence of radar clutter does not necessarily imply that targets cannot be seen on the other side of the scattering region.

17-6 Effects of Reflection

In addition to absorption, another important cause of signal attenuation in the HF band is loss of reflection from the E- and F-regions of the ionosphere (see TRAVELING DISTURBANCE in Chapter 8). Signals that normally would be returned to the receiver continue on into space. Conversely, burst-induced ionization in the E- and F-regions of the ionosphere may increase the electron density and allow reflection of signals at higher frequencies than normal.

INTERFERENCE

17-7 Noise

Thermal noise radiated by the hot fireball can produce receiving-antenna noise temperatures of several thousand degrees Kelvin for tens of seconds to several hundred seconds, depending upon the fireball altitude. A system normally will not experience problems from fireball noise unless the fireball is large enough that the antenna beam is essentially filled by the fireball and that absorption outside the fireball is significant at the frequency of interest.

Synchrotron noise may be associated with nuclear bursts that take place at very high altitudes or if the weapon debris rises to very high altitudes. The effect is noticeable only if a large number of electrons are trapped in the geomagnetic field outside the atmosphere. Only very sensitive HF receiving systems with upward-pointing antennas are likely even to detect synchrotron noise, but it may persist for weeks.

17-8 Reflection, Refraction, and Scatter

Reflection and refraction of electromagnetic (EM) waves can cause unwanted signals to reach the receiver. These signals can mask and distort desired signals. Multipath interference occurs when a desired signal travels two or more

paths. The result is severe fading and distortion. HF and VHF systems operating in a nuclear-burst environment may experience unusual multipath conditions due to E- and F-region ionization, causing highly anomalous propagation modes with consequent signal distortion. Reflection from fireball surfaces may, under certain conditions, cause multipath in the UHF band.

Signal scattering can occur as a result of irregularities in electron density. A radar signal scattered back to the receiver may mask desired target returns or may produce a false target. Signals from other transmitters may scatter into a receiver, increase the noise level, and mask desired signals. In general, scatter in and above the HF band is caused by fireballs and by beta-particle ionization regions.

SIGNAL DISTORTION

Propagation media disturbances may change the characteristics of a signal and degrade system performance. Frequency shifts, time delays, angle-of-arrival deflection, and polarization rotation are all possible effects (see PHASE EFFECTS in Chapter 8). The results may include reduction of effective system bandwidth and increased error rates when the signal is processed by the system.

Range and angular errors may be induced in radar systems by time delay and bending of the propagation direction. Generally, D-region ionization sufficient to produce signal distortion also will produce large absorption levels. At altitudes above the D-region, signal distortion (particularly range and angular errors) may occur at low or moderate absorption levels. Irregularities in electron density in and above the upper part of the D-region can change the direction of propagation and cause fluctuations in the angle of arrival of received signals (scintillation).

The significance of a change in signal characteristics depends critically on the signal

[REDACTED]

processing employed and on the system mission. The effects are most likely to be significant in systems that feature extreme accuracy and sensitivity, and depend upon sophisticated waveform processing.

SECTION II

SYSTEM CHARACTERISTICS AND EFFECTS

Nuclear environments related to the various types of military engagements affect the propagation medium and noise production differently. A detailed analysis of nuclear effects depends on specifying all of the nuclear burst and system parameters, and is beyond the scope of this chapter. However, the kinds of effects and their spatial and temporal extent can be illustrated with a limited number of examples. These examples suggest the general nature of the nuclear effects for most practical cases and will assist in identifying critical system parameters.

VLF AND LF SYSTEMS

17-9 VLF and LF Propagation

Propagation at frequencies below about 1 MHz, i.e., in the VLF, LF, and part of the MF bands, is controlled by the D-region of the ionosphere. Under natural conditions, there is a distinct difference between propagation of VLF (10 to 30 kHz) and LF (30 to 300 kHz). At VLF, the distance between the earth and the ionosphere is only a few wavelengths, and it is natural to think of these two boundaries as the walls of a waveguide. The received field is then the sum of the normal modes that have propagated to the observation point. The quantities of interest are the excitation factor (the relative energy supplied to the mode by the transmitter), the attenuation rate (loss of energy per unit distance), and the phase velocity of each mode. If the ionosphere is less than about three wavelengths from the ground, the modes are almost

equally excited, and the most important mode is always the mode of least attenuation. Lowering the ionosphere (which results from weapon-produced ionization) will usually increase the attenuation rate, and will increase the energy in the propagating modes. The effect on the total field strength depends on the trade off of these two effects. The different modes have different phase velocities, so if two modes are of almost equal strength, their sum will vary as a function of distance. The sum will be large where the two components are in phase and small where they are out of phase.

At frequencies above 30 kHz, the distance between the earth and the ionosphere is many wavelengths, and it is more convenient to think of the total field strength as the sum of the direct (or ground) wave, the first-hop skywave (energy reflected once from the ionosphere), the second-hop skywave (energy reflected twice from the ionosphere), etc. This is the same concept used at HF, but there is an important additional consideration. At LF, the downcoming skywaves diffract significantly around the curvature of the earth, so it is necessary to include them at distances that would be considered geometrically impossible at HF.

In the VLF and LF bands, the noise at the receiver is assumed to have an atmospheric source. It therefore depends upon season, time, and geographic location.

17-10 Effects of Nuclear Bursts on VLF and LF Systems

The effects on propagation of VLF and LF signals caused by nuclear detonations result from ionization produced in and below the D-region (see IONIZATION AND DEIONIZATION, Chapter 8). Usually the effects are caused by free electrons, but significant absorption also may result from ions. Depending on weapon type and burst location, prompt radiation (neutrons and X-rays) can produce D-region ioniza-

[REDACTED]

[REDACTED] tion in the general vicinity of the burst. Significant D-region ionization also can be produced in the burst region by delayed gamma rays from fission debris if the debris is above 25 kilometers altitude and by beta particles if the debris is above 60 kilometers altitude. Beta particles and Compton electrons (produced by gamma rays) can cause significant ionization in the region magnetically conjugate to the debris location. Under certain circumstances, ionization at locations very distant from the burst may result from neutron-decay betas and the dumping of trapped radiation.

[REDACTED] Blackout or complete disruption, of VLF and LF communication systems usually requires burst-produced ionization to affect a large portion of the propagation path. Since the propagation paths are typically many thousands of kilometers long, high-altitude detonations or multiple detonations dispersed over the propagation path are required to produce the necessary ionization. Degradation can be caused by reduction of signal amplitude and rapid changes in signal phase. The significance of phase changes to system performance depends critically upon the system characteristics.

[REDACTED] Usually the greatest change in signal amplitude and phase from preburst conditions occurs for nighttime conditions; however, there are little day-night differences for large weapon yields. Effects are not uniform over the frequency band. When there is sufficient ionization to cause low reflection altitudes, propagation near the lower end of the LF band appears to suffer the least degradation. When the reflection boundary is near normal height but diffuse, propagation near the lower end of the VLF band appears to be affected least. In some cases the ionization distribution along the propagation path is such that low reflection altitudes occur over part of the path and a diffuse reflection boundary over the remainder.

[REDACTED] In general, the longer the path length, the greater the probability of circuit degradation. Although there is a small probability that the signal-to-noise ratio may be increased, it will generally be reduced. Severe signal reductions can persist for hours, depending on the extent and kind of weapon-produced ionization. Equal reduction of signal and atmospheric noise may not influence system performance until the reduction in noise is so great as to render local receiver noise a determining factor.

[REDACTED] Phase shifts up to about 1,000 degrees per burst at rates as high as 1 degree per microsecond may occur for each burst. The rate of recovery is usually a few degrees per second. Systems that cannot follow these phase shifts will lose synchronization. Time to reestablish synchronization is very difficult to estimate, but may require tens of minutes or longer.

[REDACTED] The general effects of nuclear bursts on VLF and LF systems may be summarized as follows:

1. The most severe signal degradation and system outages of longest duration occur for widespread debris environments. This environment may be caused by a large-yield weapon detonated at high altitudes or by multiple detonations distributed over a large area.
2. An ionization impulse resulting from a very-high-altitude (even though low yield) detonation affects a wide area and may degrade LF system performance for tens of minutes. The propagation effects are greater at night than during the day.
3. Single detonations at altitudes below several hundred kilometers produce less severe signal degradation, unless the burst is close to the propagation path. Detonations near the surface (below about 30 km) have the least effect on VLF and LF propagation.

[REDACTED]

17-11 Spread-Debris Environment [REDACTED]

[REDACTED] Following nuclear bursts, debris can be spread over a large area if weapons are detonated above about 50 kilometers at dispersed locations. By assuming the debris to be uniformly distributed, a relatively simple model that provides useful estimates of propagation effects resulting from several bursts is obtained. The ionization affecting VLF and LF propagation is caused by beta and gamma radiation from the fission debris. This ionization can be characterized by the fission yield per unit area and the average age of the debris. Assuming the detonations occur within a few minutes of each other, a parameter w can be defined by

$$w = \frac{W_F}{A} \frac{1}{t^{1.2}}$$

where W_F/A is megatons of fission yield per square kilometer, and t is time after attack in seconds. A value for w of 10^{-7} represents a very severe attack environment. Values of w between 10^{-9} and 10^{-11} are representative of a wide range of attack conditions, and can apply over a considerable area even for relatively light attacks.

[REDACTED] Figure 17-2 shows the signal attenuation for a 4000 km path. For large values of w , the reflection altitude is low and propagation near the low end of the LF band is least affected. In the range of the more likely w value of 10^{-11} to 10^{-9} , the reflection boundary becomes more diffuse and propagation in the VLF band shows minimum effects. For daytime conditions the LF signal attenuations are somewhat smaller than for nighttime conditions when w is less than about 10^{-11} . Effects similar to those described for propagation beneath the debris occur on the opposite side of the geomagnetic equator as a result of beta-particle and Compton electron ionization (see paragraph 8-3).

[REDACTED] While the results shown are for that portion of a path under the debris, it should be noted that degradation effects will not be limited to this region. Gamma radiation will increase the size of the ionization region up to several thousand kilometers from the debris boundary. Propagation effects outside the debris region, while significant, depend on the details of the debris-path geometry.

17-12 Effect of a [REDACTED] 6300-km Burst [REDACTED]

[REDACTED] Prompt radiation from [REDACTED] burst at 6300-km altitude (one earth radius) produces an impulse of ionization over a very large region. The extent of ionization is determined by the X-ray horizon, [REDACTED]

[REDACTED] Figure 17-3 shows the signal attenuation for nighttime conditions on a 4000-km path. The ionization impulse produces a diffuse reflection boundary, and propagation near the lower end of the VLF band is affected less than at the higher end. [REDACTED]

[REDACTED] Attenuation caused by prompt radiation is much less in the daytime than at night.

[REDACTED] The phase advance caused by the ionization impulse (for times greater than 1 second after burst) is shown in Figure 17-4. At the time of the burst, the phase advance is much larger, on the order of thousands of degrees occurring in a few milliseconds.

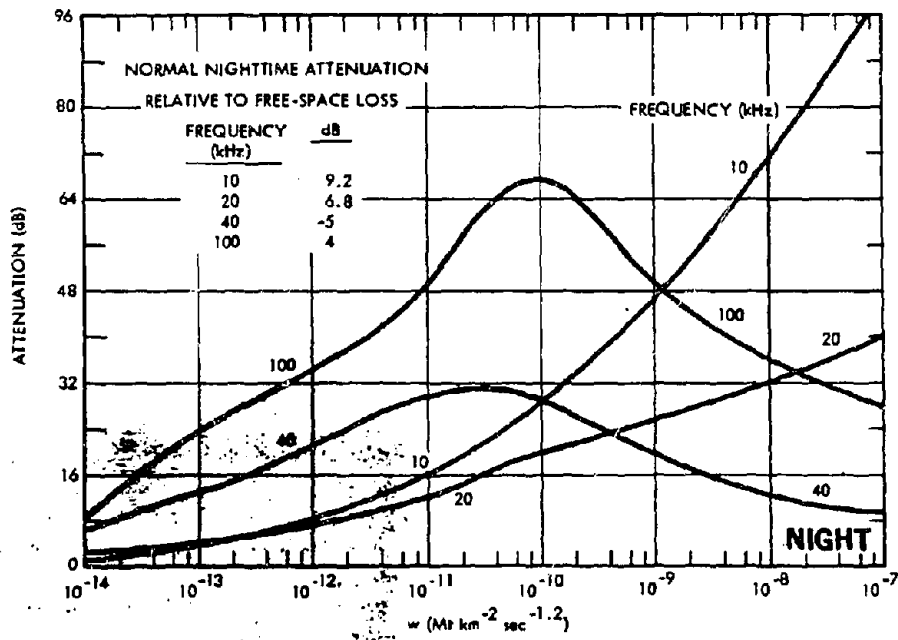
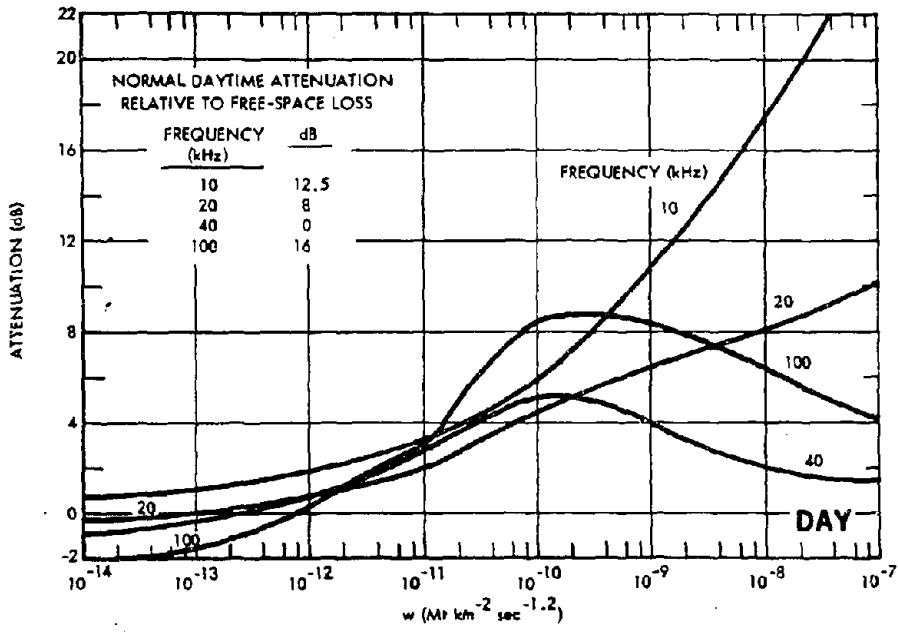


Figure 17-2. Attenuation Related to Normal Loss Due to Spread-Debris Environment, 4000-km Path Length

[REDACTED]

17-13 Effect of Detonations Below About 300 km [REDACTED]

[REDACTED] If a nuclear burst occurs below 300 km, the portion of a propagation path that is affected is generally small unless the burst is close to the path. Depending on burst location and detonation altitude, there can be two degradation periods. The first period occurs at or within few minutes of burst time and is caused by prompt radiation and gamma radiation from the fission debris. The second period occurs when the fission debris has spread sufficiently that beta particles produce ionization along the path. In general, degradation is more severe in the LF band than the VLF band. An exception to this rule occurs during the first few minutes after a large-yield burst, which can produce intense ionization along the path that will cause low reflection altitudes.

[REDACTED] When a nuclear weapon is burst on the surface, ionization is limited essentially to the fireball region until the debris reaches altitudes above about 25 kilometers, where gamma radiation can penetrate the atmosphere. Even then, the extent of ionization affecting propagation is only a few hundred kilometers, and the effects are minimal. A large number of surface bursts, such as might occur during a nuclear war, could produce widespread ionization. Propagation effects similar to those described above for the case where the fission debris has spread to large distances would be expected for such conditions.

[REDACTED] HF SYSTEMS [REDACTED]

17-14 HF Propagation [REDACTED]

[REDACTED] Propagation at frequencies between about 1 and 60 MHz is supported by the F-region of the ionosphere. Generally speaking, the HF signal is a composite of many signals propagated along ray paths with different geometries. Figure 17-5 is an example of the ray-path

geometry of a 4000-km path during the daytime at a single frequency. This multiple ray-path characteristic of HF is very important in any analysis of the susceptibility of a circuit to degradation from nuclear effects. Natural variations in the ionosphere affect the exact ray-path geometry at any specific time.

[REDACTED] Noise at HF comes from a variety of sources. Noise power in this frequency range has been conventionally calculated as a combination of propagated noise from thunderstorm centers (concentrated mostly in tropical areas) and man-made local noise. Atmospheric noise tends to be dominant at night when ionospheric absorption is less, whereas man-made noise may set the daytime level. Very often, however, the noise level is determined by other interfering signals because of congestion of the HF band. No means have been devised for quantitatively treating this latter and perhaps most important source of noise.

17-15 Effect of Nuclear Bursts on HF Systems [REDACTED]

[REDACTED] The most important phenomenon produced by nuclear bursts that affects HF systems is absorption resulting from D-region ionization. The ionization of the D-region is produced by prompt and delayed radiation. The amount of ionization depends on the altitude and the yield of the detonation (see IONIZATION AND DEIONIZATION in Chapter 8). Persistent absorption results from delayed gamma radiation when the debris is above 25 kilometers, and from beta particles when the debris is above 60 kilometers. Beta particles and Compton electrons can produce significant absorption in the region magnetically conjugate to the debris location. D-region absorption can extend over several thousand kilometers and can be important for hours after burst. For detonations above about 100 kilometers, there are often two distinguishable absorption periods: one, which starts at burst time,

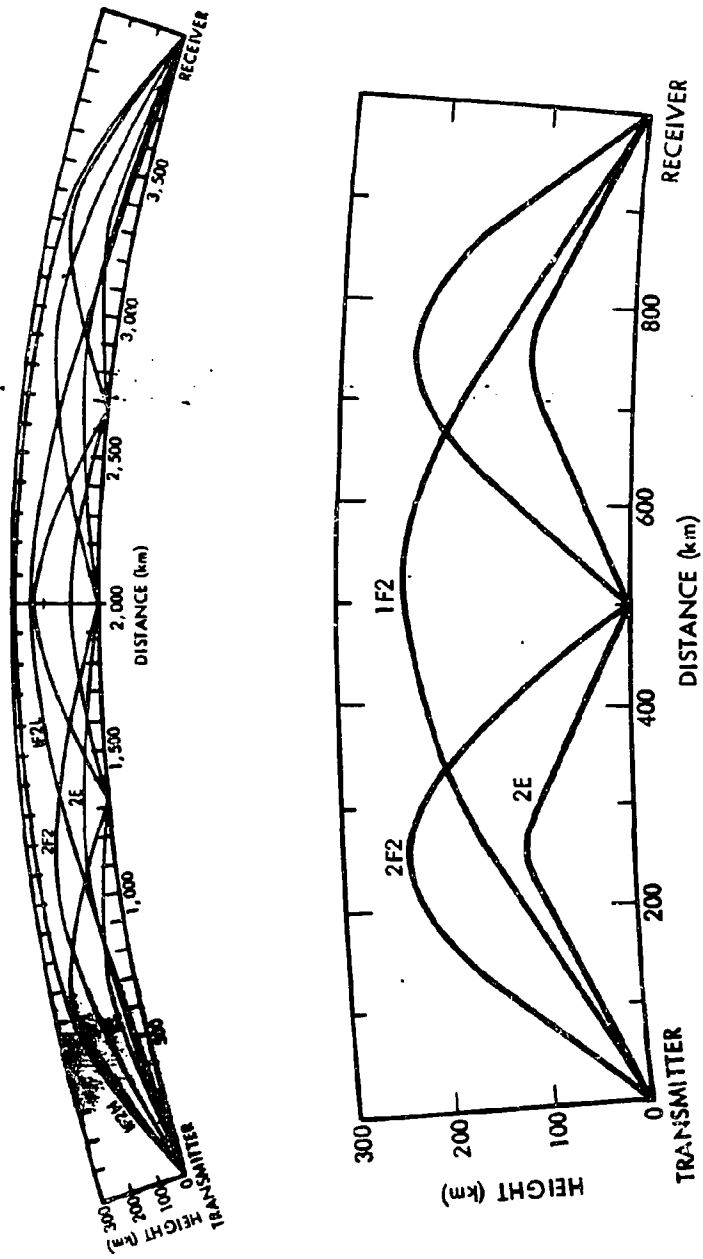


Figure 17-6. Examples of Daytime HF Ray-Path Geometry

[REDACTED]

results from ionization caused by prompt radiation and delayed gamma rays; a second results from ionization caused by beta particles. This latter starts when the fission debris has spread sufficiently that beta particles can ionize the D-region at the location of the propagation path. The duration of absorption depends on weapon yield and design, frequency, and time of day. The duration may vary from a few minutes for a small-yield weapon burst at night to several hours or more for a large-yield weapon burst during the day.

[REDACTED] Detailed calculations of signal attenuation due to D-region absorption require the determination of the absorption for each ray path connecting transmitter and receiver. The procedures given in Chapter 8 (see Problems 8-5 through 8-7) can be used to determine the absorption when the ray path geometries are specified. Since D-region ionization does not alter ray-path geometry appreciably (see paragraph 8-10, Chapter 8), the pre-burst ray-path geometry can often be used in determining absorption. However, as discussed below, changes produced by the burst in the E- and F-region electron density can alter the number and location of ray paths, and thus can affect absorption calculations.

[REDACTED] Ionization produced by a nuclear burst and traveling disturbances in the E- and F-regions of the ionosphere can produce significant changes in the E- and F-region electron densities that can last for hours (see TRAVELING DISTURBANCES IN E- AND F-REGIONS OF THE ATMOSPHERE in Chapter 8). Changes in the E- and F-region electron density can result in significant multipath effects by increasing the available ray paths and by introducing off-great-circle propagation paths. The maximum usable frequency (MUF) may be much lower than normal after nighttime detonations for ray paths that pass within several thousand kilometers of the detonation. For certain geometries and burst

conditions the MUF may be higher, perhaps up to 60 MHz. Current theoretical models do not provide reliable prediction of the MUF as a function of burst and system parameters. Oblique, frequency-sweep ionospheric sounders may allow determination of usable frequencies during disturbed conditions.

[REDACTED] While HF system performance usually will be degraded by nuclear bursts (often resulting in complete circuit outage for significant periods of time), there may be factors that tend to minimize the degradation. For example, a reduction in noise or interference may accompany a reduction in signal strength, thus tending to preserve the preburst signal-to-noise ratio. Higher frequency propagation may be possible because of increased E- and F-region ionization, and the higher frequency will be less susceptible to absorption.

[REDACTED] The general effects of nuclear bursts on HF systems are summarized below:

1. The higher the altitude of detonation, the greater and more widespread are the effects.
2. HF systems can recover from a nuclear attack, with nighttime recovery being much more rapid than daytime.
3. Intermittent propagation may occur even under severe circumstances, but the frequency range is not always predictable.
4. When ionization produced by weapon debris is not widespread (less than about 500 km) and the circuit is longer than a few thousand kilometers, the chances are good that continuous communication can be maintained after recovery from the prompt effects.
5. Multiple bursts occurring at dispersed locations and times can increase the degradation greatly and can reduce the sensitivity of the system to burst location.

The variations in the effects of nuclear bursts on

[REDACTED]

HF systems are illustrated by the descriptions of several specific examples in the following paragraphs.

17-16 Effect of Surface or Near-Surface Bursts

Single or closely spaced bursts may occur during attacks against ground targets. Weapon radiation initially is confined to a volume of space near the detonation point, and a fireball is produced that subsequently rises (see paragraph 1-12 and 1-20). Ionization produced by the burst is essentially confined to the fireball region until the fireball carries the fission debris above about 25 kilometers, where gamma radiation can penetrate the atmosphere and produce D-region ionization. The extent of this ionization is a sensitive function of debris altitude. Gamma rays produce ionization over about 200 km horizontal extent for a 1-Mt surface burst, and over about 400 km for a 10-Mt surface burst. Because the area of high absorption is small, multiple rays will be affected only if they have a common D-region intersection. In any situation where the signal propagates over multiple ray paths that are sufficiently separated in the vicinity of the absorbing area, there will be little if any effect. Calculations for long and intermediate path lengths show that it is very difficult to eliminate all propagating frequencies. In some cases it would be necessary to switch to lower rather than higher frequencies to avoid outage, but communications could be maintained.

Signal attenuation caused by surface bursts can be severe for short paths since the D-region intersections of the ray paths are close together (see Figure 17-5). Communications on certain frequencies can be disrupted for a period of hours, especially during the day.

17-17 Effect of a 30-km Burst

A [REDACTED] device detonated near an

altitude of 30 kilometers has potential as a possible penetration aid. The detonation point is sufficiently high that gamma rays will produce moderately widespread ionization even at early times. By 5 minutes after detonation, the debris will have risen [REDACTED] and beta particles can escape the debris region. Therefore, both gamma rays and beta particles are important ionization sources.

[REDACTED]

For a typical burst location, there would be two periods of pronounced absorption; the first would occur during the initial debris rise, and the second would occur when the radiation from the spreading debris reaches critical D-region points.

[REDACTED]

Because the region of increased ionization for this example is comparable to the D-region spacing between ray paths, the sensitivity to exact burst position is less critical than it is for surface bursts. The effects are still relatively limited, however, and the communication degradation does depend upon the burst location and the propagation path length.

17-18

[REDACTED]

[REDACTED]

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DNA
(X1)

DNA
(X1)

[REDACTED]

17-18 Effects of a [REDACTED] 50-km Burst [REDACTED]

DNA (S)(1)

The effects of an extremely large yield weapon can be illustrated by describing the effects of [REDACTED] at 50 kilometers. Ionospheric effects are widespread and severe in both the burst and the conjugate regions. The debris rises to approximately 150 kilometers in less than 10 minutes, and it spreads to nearly 600 kilometers radius within 15 minutes. Thereafter, the debris radius continues to increase slowly as a result of winds.

The relatively high altitude and large yield of such a burst produce immediate and severe effects.

DNA (S)(1)

[REDACTED]

The size of the absorbing region is large enough that nearly all rays along a given propagation path will be affected simultaneously, causing path orientation and path length within the region to be unimportant. Absorption effects of a similar nature also can be expected in a region on the opposite side of the magnetic equator from the burst centered at the conjugate of the burst point.

The shock wave from a nighttime explosion [REDACTED] can be expected to reduce the critical frequency of the reflection region [REDACTED]

DNA (S)(1)

[REDACTED] This condition will probably persist [REDACTED] after sunrise. [REDACTED]

[REDACTED]

If the propagation path is offset from the burst, there can be an initial period of ab-

sorption as a result of prompt and delayed gamma radiation. This period might be followed by a period of recovery to near normal conditions, and then a second period of absorption would occur as the debris expands and beta particles affect the path.

[REDACTED]

DNA (S)(1)

17-19 Effect of Multiple Multimegaton 150-km Bursts [REDACTED]

Multiple multimegaton high altitude bursts represent conditions that may result from the employment of a ballistic missile defense system. The most significant effects on HF circuits are widespread prompt ionization, widespread and intense delayed radiation, and F-region modifications. The debris will be distributed over a large altitude region, with some debris reaching altitudes above 1000 kilometers. The geomagnetic field plays an important role in determining late-time debris location (see Problem 8-7, Chapter 8).

If multiple multimegaton high altitude bursts occur, HF circuits will be interrupted over a very substantial area, essentially at burst time:

[REDACTED]

The duration of the outage for paths at these extreme ranges will be brief.

DNA (S)(1)

[REDACTED]

The particularly large radius of effects at early times results from the high altitude to

[REDACTED]

[REDACTED]

which the debris rises. Gamma radiation from the debris has a horizon of about 4000 kilometers from the burst points. Eventual expansion of the debris results in secondary outages when beta-particle ionization reaches a given path. In the region around the conjugate of the burst points beta-particle ionization is similar to that produced in the burst region. Compton electrons cause ionization which is less intense than that produced by gamma rays in the burst locale (see paragraph 8-3).

The critical frequency of the reflection region probably will be affected out to about 1000 kilometers after many large yield high altitude bursts. Significant electron density enhancement may occur near the detonation points, and electron density depletion may occur at more remote locations

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[REDACTED]

location and length of the communication path. Ionization caused by the betas emitted by the spreading debris from such a burst will result in prolonged outage of HF systems. The lowest frequencies will be out for the longest period of time.

[REDACTED]

DNA
(S)(1)

During the nighttime, the rapid decay of D-region ionization results in rapid recovery of all HF communication circuits that are not affected by beta ionization.

[REDACTED]

DNA
(S)(1)

17-20 Effect of a 1-Mt, 250-km Burst

A 1-Mt weapon burst at an altitude of 250 kilometers will result in significant propagation effects from prompt radiation, delayed radiation, and changes in the F-region. Debris will be distributed over a large altitude region; the geomagnetic field will affect the late-time debris location, with some debris being transported across the geomagnetic equator. Very intense and widespread effects will be produced on the ionosphere; hence there will be degradation of HF communication systems. However, because of the lower yield and somewhat shorter debris rise than in the case discussed in paragraph 17-18, the effects are more dependent on the

Circuits within several thousand kilometers of the conjugate of the burst point will also experience significant degradation. The absorption caused by beta-particle ionization is similar to that described for the burst region.

For this type of high-altitude burst, the E- and F-region electron densities may be increased in the region near the burst.

[REDACTED]

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[REDACTED]

[REDACTED]

reduced below the MUF at distances beyond 500 kilometers from the burst.

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(S)

17-21 Effect of a 1000-km Burst

[REDACTED] weapon burst at an altitude of 1000 kilometers would be primarily an anticommunication event. In spite of the small yield, the X-ray output is sufficiently large that even from an altitude of 1000 kilometers, significant ionization would be produced in the lower ionosphere.

The radius of effects from such a burst is much greater than individual mode separation distances; thus, the exact ray path position, path length, and orientation are not important for distances less than approximately 2000 kilometers.

DNA
(S)

[REDACTED]

SATELLITE COMMUNICATION SYSTEMS

The basic elements of a satellite communication system consist of a ground-terminal transmitter, a satellite-borne repeater, and a ground-terminal receiver. Typically, the satellite-borne equipment provides only the functions of frequency translation and amplification; signal processing and demodulation take place at the ground terminals. Gigahertz frequencies and large bandwidths are typical of satellite communication systems, but some systems may operate in the VHF and lower UHF bands.

17-22 Effects of Nuclear Bursts on Satellite Systems

The nuclear bursts of primary impor-

tance to military satellite communication systems are those that produce an intense ionization region which is intersected by the propagation paths of the relay circuit. One of the principal effects of this ionization is absorption of the propagating signal. The region of significant ray-path absorption for communication satellites operating at several gigahertz is usually confined to the fireball; however, other important absorption regions may exist for some combinations of yield and burst altitude. (See Chapter 8 for a discussion of ionization and absorption regions produced by nuclear detonations.)

[REDACTED]

DNA
(S)

D-region ionization produced by prompt and delayed radiation (beta particles and gamma rays) produces absorption that [REDACTED] depending on propagation frequency, burst altitude, and fission yield. Delayed gamma rays can affect propagation in the VHF band [REDACTED]

DNA
(S)

The extent of D-region absorption caused by beta particles is determined by the debris expansion, and this absorption can affect propagation in the VHF and UHF bands [REDACTED]

In modern low-noise receivers, it is often the noise appearing at the terminals of the receiving antenna that will set the limit on the overall performance of the system. As a result, fireball thermal noise can be significant in degrading the performance of satellite communication systems (see ELECTROMAGNETIC RADI-

[REDACTED]

[REDACTED]

ATIONS in Chapter 8). The amount of electromagnetic thermal radiation reaching the receiver antenna depends on the effective fireball temperature at the frequency of interest (a function of temperature and emissivity) and on the amount of attenuation between the fireball and the antenna. Antenna temperature generally will be less than the effective fireball temperature as a result of absorption that occurs outside the fireball and the effect of antenna gain in the direction of the fireball.

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(K-1)

[REDACTED]

The group time delay associated with signal propagation through a plasma usually is frequency dependent. This causes phase distortion of angle-modulated signals (frequency and phase modulation are forms of angle modulation), resulting in what is termed intermodulation noise. This frequency-dependent time delay, or dispersion, also results in envelope distortion for pulse transmission through a plasma. Hence, another effect of burst-produced ionization that may be of importance to angle-modulated multichannel satellite systems of large channel capacities is the intermodulation distortion noise. The strength of this intermodulation noise is determined largely by the integrated electron density along the ray path and the modulation parameters. Typically, it is the late-time, high-altitude fireball ionization that may give rise to this dispersion effect. Similarly, satellite digital-communication systems may encounter pulse distortion when propagating through burst-produced ionization, which in

turn may result in large decoding error rates. The dispersive medium may affect pulse amplitude systems because of envelope distortion. The magnitude of the pulse distortion is determined by the integrated electron density along the ray path, the carrier frequency, and the pulse width.

[REDACTED] Time-variant time delays due to the structured and filament-like behavior of high-altitude fireball striations may be a possible source of degradation to satellite communication systems; no estimate has been made of these effects because of the lack of data from which to scale results. The effects of time-variant time delays would be to introduce channel noise of a nature similar to intermodulation noise or adjacent-channel interference.

17-23 Nuclear Effects on Two Typical Satellite Systems [REDACTED]

[REDACTED] Two hypothetical but typical satellite systems have been selected to illustrate many of the problems of satellite communication in a nuclear warfare environment. System A (see Table 17-1) represents a high-volume military communication system. The mission requires continuous coverage between virtually every pair of points on the earth's surface. The system provides a tactical quality of voice communications.

[REDACTED] System B (see Table 17-2) operates in the UHF band at 400 MHz. It employs an 8-hour circular communications orbit. The power requirements, antenna size, channel capacity, and grade of service provided represent a tactical, transportable communication system.

[REDACTED] The systems considered employ Frequency Division Multiplex-FM (FDM-FM) as a means of carrier modulation. Voice channels are frequency multiplexed onto a single baseband using subcarriers. This baseband is then applied to a linear frequency modulator to modulate the transmitter RF carrier.

Table 17-1. [redacted] Satellite Communications Link Description, System A [redacted]

System Parameters	Description
Frequency	4 GHz
Channel capacity	300 duplex channels
Baseband	60 to 1300 kHz
Modulation format	FDM-FM
RMS frequency deviation	0.9 MHz
FM threshold	12 dB
Ground antenna	80-foot dish
Ground transmitter power	10 kw
Ground receiver I-F bandwidth	15 MHz
Ground receiver system noise temperature	100°K
Satellite receiver noise figure	10 dB
Satellite antenna (toroidal pattern)	5 dB gain
Satellite transmitter power	25 watts
Satellite altitude (synchronous)	35,788 km

Table 17-2. [redacted] Satellite Communications Link Description, System B [redacted]

System Parameters	Description
Frequency	400 MHz
Channel capacity	12 duplex channels
Baseband	0 to 60 kHz
Modulation format	FDM-FM
RMS frequency deviation	27.4 kHz
FM threshold	12 dB
Ground antenna	30-foot dish
Ground transmitter power	10 kw
Ground receiver I-F bandwidth	0.672 MHz
Ground receiver system noise temperature	250°K
Satellite receiver noise figure	10 dB
Satellite I-F bandwidth	1 MHz
Satellite antenna (toroidal pattern)	-3 dB
Satellite transmitter power	20 watts
Satellite altitude (8-hour circular orbit)	13,896 km

Table 17-3 summarizes outage times for the two systems

[redacted]

[redacted]

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[REDACTED]

Table 17-3. [REDACTED] Estimated Outage Times for Fireball Intersection of the Propagation Path [REDACTED]

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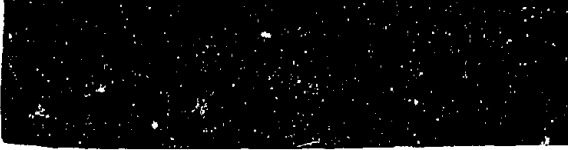
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Figures 17-6 and 17-7 illustrate two degradation mechanisms: fireball absorption and fireball noise. Figure 17-6 shows signal-to-noise ratio for Systems A and B.

The fireball is located such that the ray path traverses the fireball when it has stabilized in altitude. Figure 17-6 also shows, for reference, the absorption along the ray path.



Figure 17-7 shows signal-to-noise ratio and received noise for Systems A and B.



TROPOSCATTER COMMUNICATION SYSTEMS

Tropospheric forward-scatter communications are used for communications and military purposes in locations where the nature of the terrain makes other means of highly reliable communication difficult.

Figure 17-8 shows the geometry for a troposcatter link. Propagation from transmitter to receiver is via scatter in the common volume in the troposphere.

17-24 Effects of Nuclear Bursts on Troposcatter Systems

Three potential sources of degradation of troposcatter communication systems are signal absorption, fireball thermal noise, and multipath interference via fireball scattering.



Since troposcatter systems typically operate between a few hundred MHz and a few GHz, only the regions of intense ionization will produce appreciable signal absorption. The ionization resulting

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[REDACTED]

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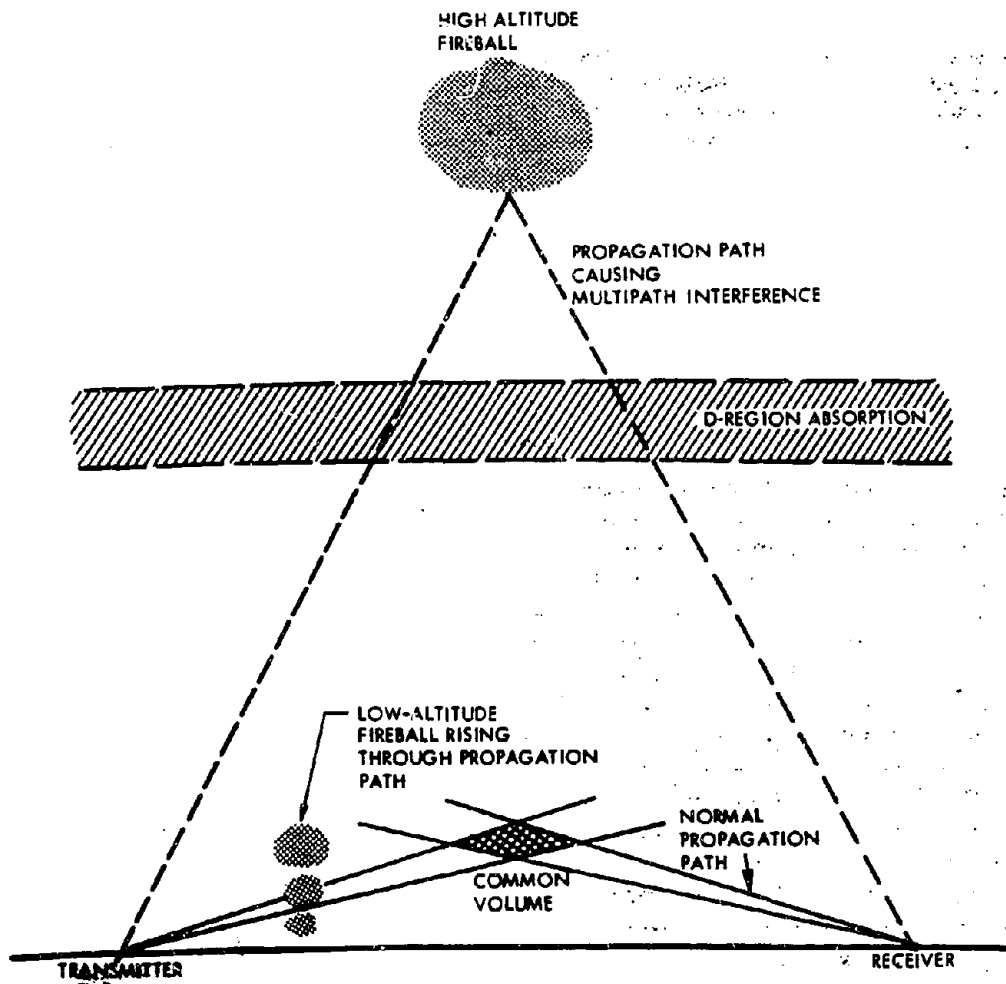


Figure 17-8. Illustration of Troposcatter Geometry

[REDACTED]

from a low-altitude nuclear burst is largely confined to the immediate vicinity of the fireball; consequently, in order to obstruct troposcatter communications as a result of ray-path absorption, the fireball must be within the scatter path.

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[REDACTED]

In low-noise receivers, fireball thermal noise may degrade the performance of troposcatter communication systems significantly. The amount of electromagnetic thermal radiation reaching the receiver antenna depends on the effective fireball temperature at the frequency of interest (a function of temperature and emissivity) and on the amount of attenuation between the fireball and antenna.

[REDACTED]

There are no significant differences between day and night effects for troposcatter systems.

17-25 Nuclear Effects on Three Typical Troposcatter Systems

[REDACTED] Three typical troposcatter communication systems have been selected to illustrate propagation effects for selected weapon environments. System A is representative of a high-quality commercial scatter system; System B is representative of a tactical system; and System C is representative of a long-distance system. The system characteristics are summarized in Table 17-4.

[REDACTED] Table 17-5 summarizes the effects on the typical systems for several burst environments. There are essentially no differences between day and night effects. The amount of degradation depends on the fireball/debris geometry, which is variable with regard to size, shape, and location. The magnitude of multipath attenuation also depends on the antenna pattern (in the examples, the side-lobe gain was taken to be that of an isotropic antenna).

IONOSCATTER COMMUNICATION SYSTEMS

[REDACTED] Ionoscatter systems provide intermediate-distance radio service of 4 to 16 channels of teleprinter and/or a single voice channel. Figure 17-9 shows the geometry for an ionoscatter link. Propagation between transmitter and receiver occurs via scattering from a common volume in the D-region.

[REDACTED] The ionoscatter system considered here transmits at a continuous low data rate via a scatter signal that is always present, although weak and variable. The ionospheric scatter mode is fundamentally most suitable for low-data-rate teleprinter operations. High-quality voice communications via ionospheric scatter cannot be

Table 17-4. Troposcatter Communication Link Description

System Parameter	System A	System B	System C
Frequency	2 GHz	900 MHz	400 MHz
Path length	300 km average per hop, 6 hops	150 km, 1 hop	600 km, 1 hop
Channel capacity	120 channels	24 channels	12 channels
Power	10 kw	1 kw	100 kw
Antennas	80-foot dish	18-foot dish	120-foot dish
Antenna height	30 meters	30 meters	30 meters
Diversity	Quad, space	Dual, space	Quad, space
FM threshold	12 dB	8 dB	12 dB
Receiver noise figure	9 dB	9 dB	2.5 dB
Baseband	60-552 kHz	12-108 kHz	12-60 kHz
Modulation format	FDM-FM	FDM-FM	FDM-FM
RMS frequency deviation	362 kHz	63.5 kHz	35.3 kHz
I-F bandwidth	6 MHz	1.3 MHz	775 kHz

achieved with reasonable transmitter power.

Ionoscatter systems typically operate at frequencies just above the E- and F-layer MUFs to eliminate multipath reflections and HF interference.

17-26 Effects of Nuclear Bursts on Ionoscatter Systems

As a result of their reliance on D-layer scattering mechanisms, ionoscatter systems are very susceptible to low-level residual ionization from a nuclear explosion. In view of the very small margin of operation above receiver threshold, usually limited by galactic noise, such systems are vulnerable to abnormal absorption along the scatter path and/or within the scattering volume. Prediction of effects in a nuclear

environment is very difficult, because the ionospheric scatter phenomena in the natural environment are not well understood.

The low frequencies employed by ionoscatter systems (about 35 to 50 MHz) allow appreciable absorption, even at low levels of residual ionization. Prompt radiation, delayed gammas from fission debris if the debris is above 25 km, and beta particles if the debris is above 60 km can all cause significant D-region ionization. If the debris is above 60 km, the betas will usually be more important than the gammas, and about one-half of the betas will be deposited in the region magnetically conjugate to where the debris is located.



Table 17-5. Approximate Extent and Duration of Effects on Troposcatter Communications, Assuming Proper Burst Placement

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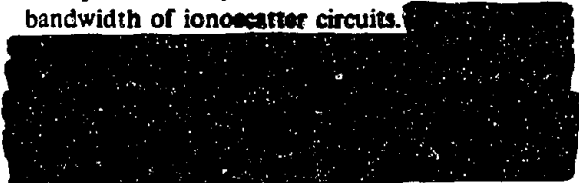
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(S)(1)



Increased E- and F-region ionization caused by prompt radiation and traveling disturbances from a nuclear detonation may result in multipath effects, which decrease the effective bandwidth of ionoscatter circuits.

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Electromagnetic thermal radiation from fireballs is usually not important to ionoscatter systems because of the high ambient noise environment.

17-27 Nuclear Effects on Typical Ionoscatter Systems

The ionoscatter system selected as an example uses two-frequency operation: 35 MHz for low transmission loss, and 60 MHz to avoid multipath interference at times of high solar activity.

The system parameters are summarized in Table 17-6. For digital communication, the encryption and order of diversity are perhaps the most important parameters that influence system performance. Because of the large variations in system performance with path length, results for 1000-, 1500-, and 2000-km links are considered. The antennas of the system consid-



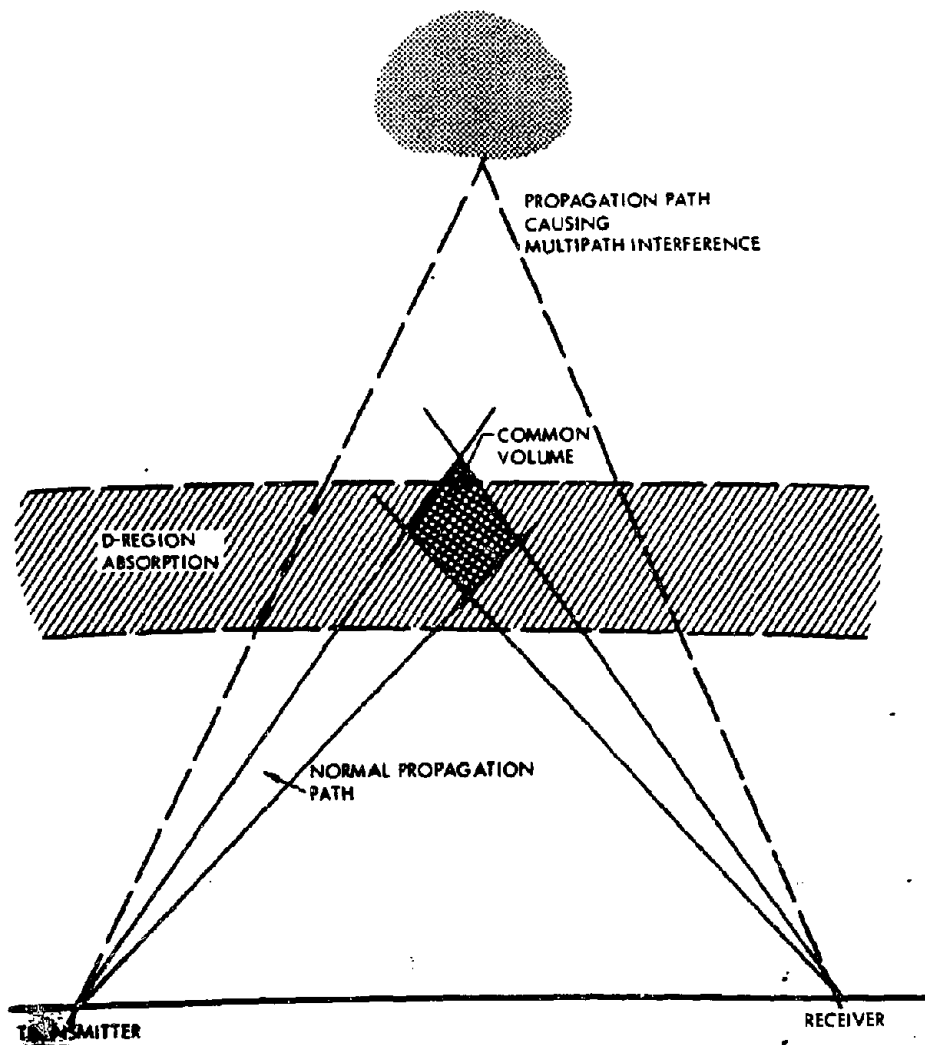


Figure 17-8. Illustration of Ionoscatte Geometry

[REDACTED]

Table 17-6. Ionoscatter Communications Link Description [REDACTED]

System Parameters	Description
Frequency	35 or 60 MHz
Path lengths	1,000, 1,500, 2,000 km (three systems)
Channel capacity	16 channels, teletype
Power	60 kw
Antenna gain	19 dB
Antenna 3-dB beamwidths	45 degrees vertical, 11 degrees horizontal
Polarization	Horizontal
Diversity	Dual, space
Receiver noise temperature	450°K
Receiver noise bandwidth	1.2 kHz
Modulation format	TDM-FSK
Frequency shift	6 kHz mark-space
Demodulator	Dual filter, optimal without Doppler spread
Radiated signal element length	1.7 milliseconds
Transmission rate	600 bauds
Coding and synchronization	Standard 5-unit, start-stop neutral code

[REDACTED] ered here are aligned along a great-circle path. Each terminal of an ionoscatter link is capable of duplex transmission.

[REDACTED] Table 17-7 summarizes the effects of several burst environments on the system described in Table 17-6. These effects show a strong dependence on the location of the burst with respect to the normal scatter path and on the scatter path length.

[REDACTED] Thermal noise from the fireball has negligible effect on this system because of the high cosmic noise levels. Effects of scattering from high-altitude fireballs, field-aligned ionization, or enhanced E- and F-region electron densities that may produce multipath interference are not in-

cluded in Table 17-7 because the phenomena are not sufficiently understood.

[REDACTED] The most serious difficulty in predicting ionoscatter propagation characteristics in a nuclear environment is lack of understanding of the mechanisms involved in normal propagation.

[REDACTED] RADAR SYSTEMS [REDACTED]

[REDACTED] Radars are used in a wide variety of missions, including surveillance, target acquisition, navigation, tracking, fire control, discrimination between true targets and decoys, guidance and control, and fuzing. The radars may be ground-based or airborne. Their frequency usually is above the HF band with line-of-sight propaga-

[REDACTED]

Table 17-7. [REDACTED] Approximate Outage Times 1000-, 1500-, and 2000-km Ionosscatter Links, Assuming Proper Burst Placement [REDACTED]

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[REDACTED] tion paths. An exception is over-the-horizon radar (OTH or OHR), which operates in the HF band and uses E- and F-region refraction to detect objects at long ranges. Nuclear-weapon effects on over-the-horizon radars correspond to effects on [REDACTED] systems, described earlier in this section. OTH radars may be used for early detection of targets before detonation of nuclear weapons, and to provide supplementary information to ballistic missile defense radars at later times.

[REDACTED] The choice of parameters to be used (frequency, radiated power, antenna beam shape, pulse waveforms, etc.) depends on the function intended for the system. Acquisition radars are designed to maximize the initial detection range and angular coverage. These radars generally use lower frequencies than tracking systems and have less stringent requirements for measurement accuracy. Tracking and discrimination radars require high measurement accuracy, and they generally use as high a frequency as

[REDACTED]

[REDACTED]

possible. Discrimination radars may use complex waveforms and signal processing to estimate the nature of the incoming object. An important parameter related to radar susceptibility to nuclear-weapon effects is the altitude of the region of space (sometimes called the battle space) from which target echoes are to be received.

[REDACTED] In view of the different parameters and accuracy requirements for the different types of systems, the significance of weapon effects depends on the radar function. For example, fairly low levels of D-region ionization can cause sufficient absorption to reduce the initial detection range of an acquisition radar without affecting track radars. Levels of clutter, scintillation, and dispersion effects that are too small to affect acquisition radars may degrade discrimination radars seriously.

[REDACTED] Radars associated with detection of aircraft or surface targets usually will not experience signal degradation, since the propagation paths are below altitudes where persistent or widespread effects are caused by nuclear weapons (about 25 km). Fireballs from surface or air bursts may interdict the propagation path, but the small size of low-altitude fireballs and the relative motion between the rising fireball and the propagation path will usually limit outage to a few seconds. Blast, thermal, and nuclear radiation damage generally will be more significant for such systems when weapons are detonated close enough to interdict the propagation path.

17-28 Ballistic Missile Defense Systems [REDACTED]

[REDACTED] Ballistic missile defense (BMD) systems can be categorized conveniently according to the size of the region defended. Area and regional defense systems are designed to protect a large area, such as one or more cities. The functions of detection, tracking, and discrimination of incoming objects are performed at as great a range as possible to allow the area to be defended with a minimum number of radars and interceptor

missile sites, and to minimize the damage to the defended area from detonation of intercept weapons. Initial detection ranges are typically a few thousand kilometers (approximately 10 minutes before impact of the incoming object). Intercept of those objects designed as threatening usually is above about 50 kilometers.

[REDACTED] Hardsite defensive systems are designed to protect a small area, usually hardened against direct damage effects (blast, thermal, etc.). Information concerning threatening objects may be transferred to the system from area defense radars. Since the defended site is hardened, intercept altitudes usually are below 30 kilometers and may be as low as a few kilometers. The system typically is designed to be able to perform acquisition, tracking, and discrimination functions after incoming objects are below 100 kilometers. High-performance interceptor missiles and data handling systems are used.

17-29 Nuclear Effects on Area Defense Systems [REDACTED]

[REDACTED] Nuclear weapon effects on area-defense radars may be caused by interceptor weapons (self-blackout) or by penetration aid weapons used by the offense. Although interceptor weapons are designed to minimize propagation effects on defensive radars, the use of a number of interceptor weapons in certain locations can cause significant problems. In the cases of area and regional defense systems, where interceptor detonation altitudes are high, the degradation mechanisms include absorption in the fireball and the D-region, scattering in the fireball and the E- and F-regions, noise, and clutter interference. Scattering and beam spreading can produce attenuation even in the absence of absorption; these propagation effects also produce scintillation of various kinds (amplitude, phase, angle, etc.). Receiver response to these effects will be similar to that associated with multipath. Absorption and scattering appear to be the most significant of the effects.

[REDACTED]

[REDACTED]

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Whether the interceptor fireball will interdict the radar propagation path depends on the spacing of incoming objects, the interceptor weapon yield and detonation altitude, and the geometrical relation between the radar and the threat approach azimuth.

[REDACTED]

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D-region ionization caused by prompt and delayed radiation can be a significant cause of absorption, because for typical geometries the propagation path must traverse the D-region. D-region absorption scales inversely with frequency squared and is essentially negligible for frequencies above a few gigahertz. At a few seconds after burst, the most intense D-region absorption is caused by beta particles. As discussed in paragraph 8-4, the beta-particle ionization region is offset horizontally from the debris region by an amount that is determined by the orientation of the geomagnetic field and the height of the debris above the D-region. Intercept altitudes that place the beta-particle ionization region along the propagation path to successive objects can produce significant signal attenuation as a result of absorption after each intercept burst. Both the location of the ionization region and the propagation path are moving, and the duration of absorption is determined by the length of time the propagation path remains in the beta-particle ionization region. Refraction effects from D-region ionization are generally

negligible, unless the level of ionization is large enough to also cause large signal attenuation.

Prompt radiation from bursts detonated above about 100 kilometers increases the electron density in the E- and F-regions. The horizontal extent of the affected region depends on the burst altitude, weapon yield, and weapon design. While absorption resulting from E- and F-region ionization outside the fireball is small for radar frequencies, refraction or bending of the propagation path will cause angular errors. Even very small elevation and azimuth errors can result in significant interceptor miss distances.

Interference and signal distortion also may be caused by noise (fireball thermal radiation), clutter, dispersion, and scintillation. While noise from fireball thermal radiation does not appear to be a significant problem for military radar systems, the conclusion should be reviewed for specific systems, particularly if low-noise receivers are used. Clutter returns can be orders of magnitude larger than target echoes and may mask the desired echo or appear as false targets. While it appears that antenna side-lobe rejection and doppler discrimination techniques can be used to reject clutter returns, these techniques may increase the data processing required by a substantial amount. Signal distortion caused by dispersion appears to be a secondary effect for acquisition and track radars, but it may degrade the performance of discrimination radars. Scintillation may cause pulse-to-pulse fluctuation in the apparent direction of the target. Computational models for scintillation are currently incomplete.

The computational models given in Chapter 8 can be used to estimate fireball absorption for ray paths traversing the fireball or D-region. While effects other than absorption are discussed in Chapter 8, computational models are not given because of the complexity of the scaling. Analysis of radar performance in a nuclear environment usually is done with computer

[REDACTED]

codes to facilitate the large number of computations required.

An example of the results of code calculations is provided below to illustrate the types of effects and the sensitivity of the effects to radar and burst parameters. The example is not intended to model an actual engagement, but it provides representative nuclear environments that might be produced by penetration aid or interceptor weapons. The geometry chosen for the example is shown in Figure 17-10. The threat trajectory (path of an incoming object) is in the direction of the geomagnetic field. One radar is located at the defended target and another is offset from the target to view the incoming object from the side.

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As the incoming object approaches the target a series of nuclear bursts are assumed to occur at a fixed altitude on the trajectory.

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(S)(1)

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Figure 17-11 shows the signal-to-noise ratio and the elevation errors calculated for the radar located at the target. Results are shown for bursts occurring at two detonation altitudes. The propagation path from the radar to the incoming object traverses beta-particle ionization regions.

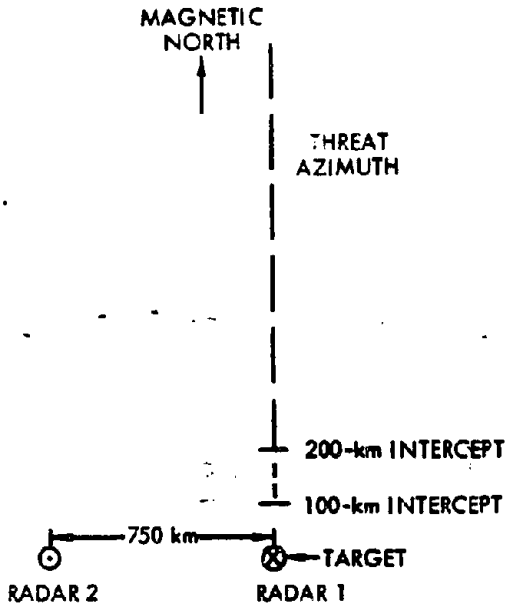


Figure 17-10. (U) Plan View of Radar and Target Geometry (U)

As previously mentioned, refraction due to E- and F-region ionization can cause angular errors that affect the defense's ability to predict the location of incoming objects and perform intercepts. Figure 17-11 shows the elevation errors computed for the radar located at the target.

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[REDACTED]

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[REDACTED]

Figure 17-12 shows the signal-to-noise ratios and elevation errors calculated for the offset radar. Because of the offset, the propagation path does not traverse beta-particle ionization regions or fireball regions, and signal attenuation is due to ionization caused by prompt radiation and delayed gamma radiation.

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(S)(1)

[REDACTED]

The above example does not show the dependence of system performance on the type of burst, the spacing and number of incoming objects, or the location of the threat azimuth with respect to the geomagnetic field, all of which can be significant. Further, the calculations for the example were based on the assumption that the phenomenology for each weapon was independent of previous weapons.

DNA
(S)(1)

[REDACTED]

It is expected that modifications of burst phenomenology in a sequential-burst environment will be important. Models for such environment are under development (see Appendix E for code listings).

[REDACTED] some field simulation has been performed by releasing barium in the ionosphere (at altitudes between 100 and 200 km) in order to produce structured plasmas. The resulting plasma does not produce significant absorption, but it does tend to striate along the geomagnetic field to produce structure

DNA
(S)(1)

[REDACTED]

This permits at least qualitative simulation of scattering effects.

[REDACTED]

17-30 Nuclear Effects on Hardsite Defense Systems

[REDACTED]

DNA
(S)(1)

The angular extent of the region obscured by the fireball is shown in Figure 17-13 as a function of detonation altitude for a typical sight line. The solid angle subtended varies as a function of time due to rise and expansion of the fireball (see Problem 8-1, Chapter 8). The magnitude of the variation is not great, however, and the values of solid angle shown in Figure 17-13 are representative of those occurring for the first few tens of seconds after detonation.

[REDACTED]

DNA
(S)(1)

[REDACTED]

[REDACTED]

Deleted

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Figure 17-13. [REDACTED] Solid Angle Obscured by 10-kt Intercept [REDACTED]

[REDACTED]

DNA
(S)(U)

[REDACTED] Penetration-aid weapons (precursors) detonated between about 20 and 50 kilometers can interfere with detection, track, and discrimination functions, and can reduce the reaction time available to the defense.

DNA
(S)(U)

Clutter returns and thermal noise from the fireball are potential degradation mechanisms for area defense systems. The use of narrowbeam antennas and signal processing will generally prevent degradation, but detailed analyses of system performance for specific scenarios and radar geometries are required.

[REDACTED]
Denial of all information to the defense is very difficult

[REDACTED]

DNA
(S)(U)

[REDACTED]

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